4-2013

Using the Radial Velocity to Search for Orbiting Planets Around Mira

Emma Molden

Follow this and additional works at: http://digitalcommons.morris.umn.edu/urs_2013

Part of the Astrophysics and Astronomy Commons

Using the Radial Velocity to Search for Orbiting Planets Around Mira

Emma Molden (Dr. Gordon McIntosh, Advisor)
University of Minnesota, Morris   The Australia National Telescope Facility

Abstract

We researched radio astronomical data from the star Omicron Ceti, more commonly known as Mira, to determine if there is evidence for orbiting planets. There is a variation in the silicon monoxide maser radial velocity of Mira that could have been due to the effect of orbiting planets. We analyzed the radial velocity data collected from Mira over the past forty years. The data were examined for periodicities. A periodicity refers to a repeating pattern within the data. Three possible frequencies were found. Each frequency within the star had the potential to be a pattern caused by an orbiting planet. The three frequencies were approximated with three sine waves. The radial velocity versus time was fit with a curve that was the sum of the three sine waves. The amplitudes of the fit sine waves model the change in velocity centroid of Mira possibly due to orbiting planets. From the wave amplitudes the masses of the suspected planets were estimated. If the periodicities of Mira were caused by orbiting planets, two of the "planets" would be about one twentieth the mass of Mira and the other "planet" would be about one fifth the mass of Mira. The amplitudes of the three fit sine waves are too large to be caused by orbiting planets. The changes in the velocity of Mira are probably due to periodicities within the star.

Introduction

Mira has a silicon monoxide gas present in the atmosphere. The silicon monoxide contributes to the spectral line emission, at a microwave frequency, from Mira that is referred to as a maser. The raw maser data were analyzed to become the velocity centroid data needed for the rest of this research project. The data originated when the maser emissions of Mira were recorded in about one hour intervals. Let it be noted that in order for these masers to be observed and recorded by a telescope on Earth, they needed to be perpendicular to the plane of the sky. As a result, the "planets" orbiting Mira were assumed to be orbiting perpendicular to the plane of the sky as well. Next, a weighted average of the maser emissions were calculated from the one hour interval and predicted to be the velocity centroid during that given time period. This process was repeated multiple times starting in 1970s until the most recent data was recorded in 2012. Figure 1 shows the variation in the velocity centroid of Mira. The data were observed to have a possible pattern that indicated a circular motion of the star. It was hypothesized that the variation in velocity centroid was caused by orbiting planets. Further investigation was done to determine if a repeating patter was mathematically consistent with an orbiting planet. Since multiple patterns were present, there was hypothesized to be multiple planets present. One period in the data represents one orbit, or period, of the "planet" around Mira.

Figure 1: Unevenly sampled velocity centroid data from Mira over a range of forty years.

Methods

- The Lomb-Scargle program in Matlab was used to find the significant frequencies in the unevenly spaced data. It is more difficult to find a pattern in data that is unevenly sampled. The Lomb method evaluates the data at each data point rather then in time intervals, to account for the unevenness. First in the analysis, the mean and variance are analyzed. Then, the Lomb normalized periodogram is found using the mean variance, and constant τ. The constant τ is a compensation that makes the data independent of any shifting in time. The normalized periodogram was found to have an exponential probability distribution. As a result, the probability that a solution of the normalized periodogram is less than a specific value is known as the "false-alarm probability". A small "false-alarm probability" specifies a significant frequency in the data. Three frequencies were found in the unevenly spaced data.

- The data were fitted with the sum of three sine waves corresponding to the three frequencies. Three parameters were fit for each sine wave: amplitude (A), phase shift (P), and a constant (C). The following curve was plotted with the velocity centroid data to give figure 2.

$$Y = C + A_1 \sin(2\pi f_1 x + P_1) + A_2 \sin(2\pi f_2 x + P_2) + A_3 \sin(2\pi f_3 x + P_3) \quad (1)$$

- The inverse of the frequencies found in Matlab were calculated to give the period of orbit for each of the "planets". A frequency represents one complete cycle in the velocity centroid data, associated to one complete cycle in a planetary orbits, or period.

- Kepler's Third Law of Planetary Motion relates the distance of a planet from the star and the planets period of orbit. Specifically, the square of the orbital period is proportional to the cube of the semi-major axis of the orbit: $p^2 \propto a^3$. The constant of proportionality is defined to be the mass of the star in solar masses.

$$\frac{a^3}{P^2} = M_s \quad (2)$$

- The velocity of the "planet" was estimated by dividing the circumference of the orbit, with the semi-major axis as the radius, by the period, the time taken for one period.

$$V_p = \frac{2\pi a}{p} \quad (3)$$

- The velocity of Mira due to each of the "planets" is the amplitude associated with each frequency. The amplitude parameter in a sine wave function represents the variation in the dependent variable. In this case, the amplitudes are the variation in the velocity centroid data, also known as the circular velocity of Mira.

- In a planet-star system a planet and star rotate around the same center of mass. By properties of two masses rotating around a center of mass, the product of the mass and distance from the center of mass must be equal for the star and planet. Also, in the planet-star system, the star and planet have the same period. Making the product of the mass and velocity equal.

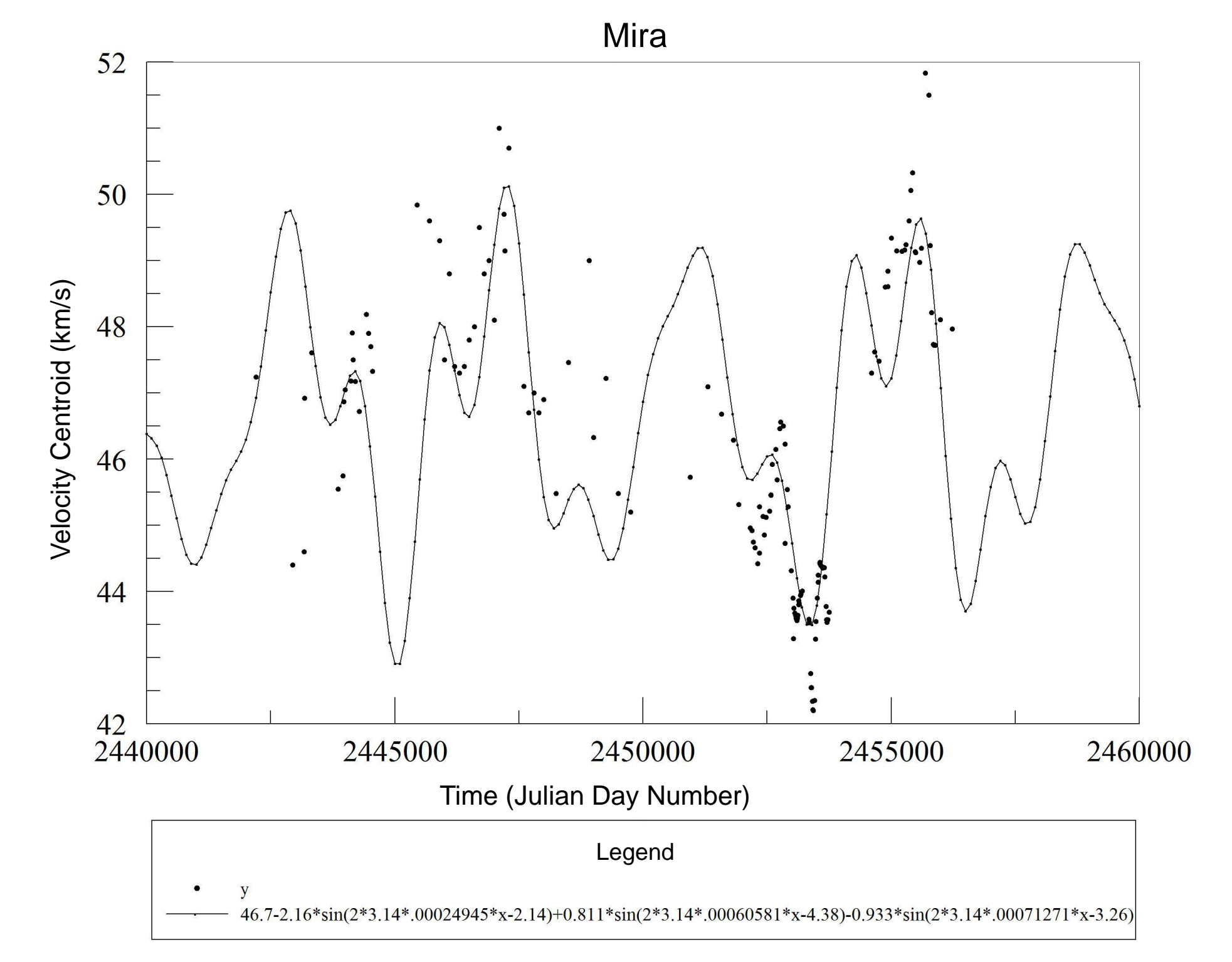$$M_p \left(\frac{d_p}{p}\right) = M_s \left(\frac{d_s}{p}\right) \quad (4)$$

Mopra Telescope operated by Australian National Telescope Facility in Coonabarabran

Figure 3: Velocity centroid data from Mira fit with the three significant frequencies approximated as the sum of three sine waves.

Results

The velocity inflicted on Mira by each of the "planets" was divided by the calculated velocity for each of the "planets". This fraction was set equal to the mass of the "planet" over the mass of Mira, as shown in equation 4. Note that the mass of Mira is 2.35×10^{30} kg. The mass values found for each of the "planets" was then compared to the mass of Mira. The following results were found.

Planet	Mass (kg)	Proportional to the Mira
1	3.54E+29	0.2
2	9.98E+28	0.04
3	1.09E+29	0.05

Conclusions

One fifth, one twentieth, and one twenty-fifth the size of Mira are too large to be the masses of orbiting planets. The below table shows the proportion of the two most massive planets in our solar system to the sun. Jupiter is the largest planet in our solar system with a mass of 1.9×10^{27} kg which is one thousandth the size of the Sun of 2.0×10^{30} kg. The most massive planet ever discovered is thirteen times the mass of Jupiter orbiting around a star, Kappa Andromedae, two and a half times the mass of the Sun. The mass of the predicted "planets" orbiting Mira are not on the same order as any planets in our solar system or ever discovered.

Planet	Mass (kg)	Proportional to the Star
Jupiter	1.8986E+27	0.001
Saturn	5.6846E+26	0.0003
κ And b	2.4681E+28	0.005

- The periodicities are too large to be the result of orbiting planets.
- The periodicities may be due to a natural periodicity within Mira.

References

- AAVSO Bulletin 74: Predicted Dates of Maxima and Minima of Long Period Variables 2011
- Noble, Ben. "13.8 Spectral Analysis of Unevenly Sampled Data." *Numerical Methods*. New York: Interscience, 1964.
- Shoelson, Brett. *Lombscargle.m*. 29 Oct. 2001. Matlab Program.
- Saragoitis, Christos. *Fastlomb* and *Lomb*. 22 Nov 2008. Matlab Program.
- Nasa. *Astronomers Directly Image Massive Star's 'Super-Jupiter'*. 19 Nov 2012. nasa.gov
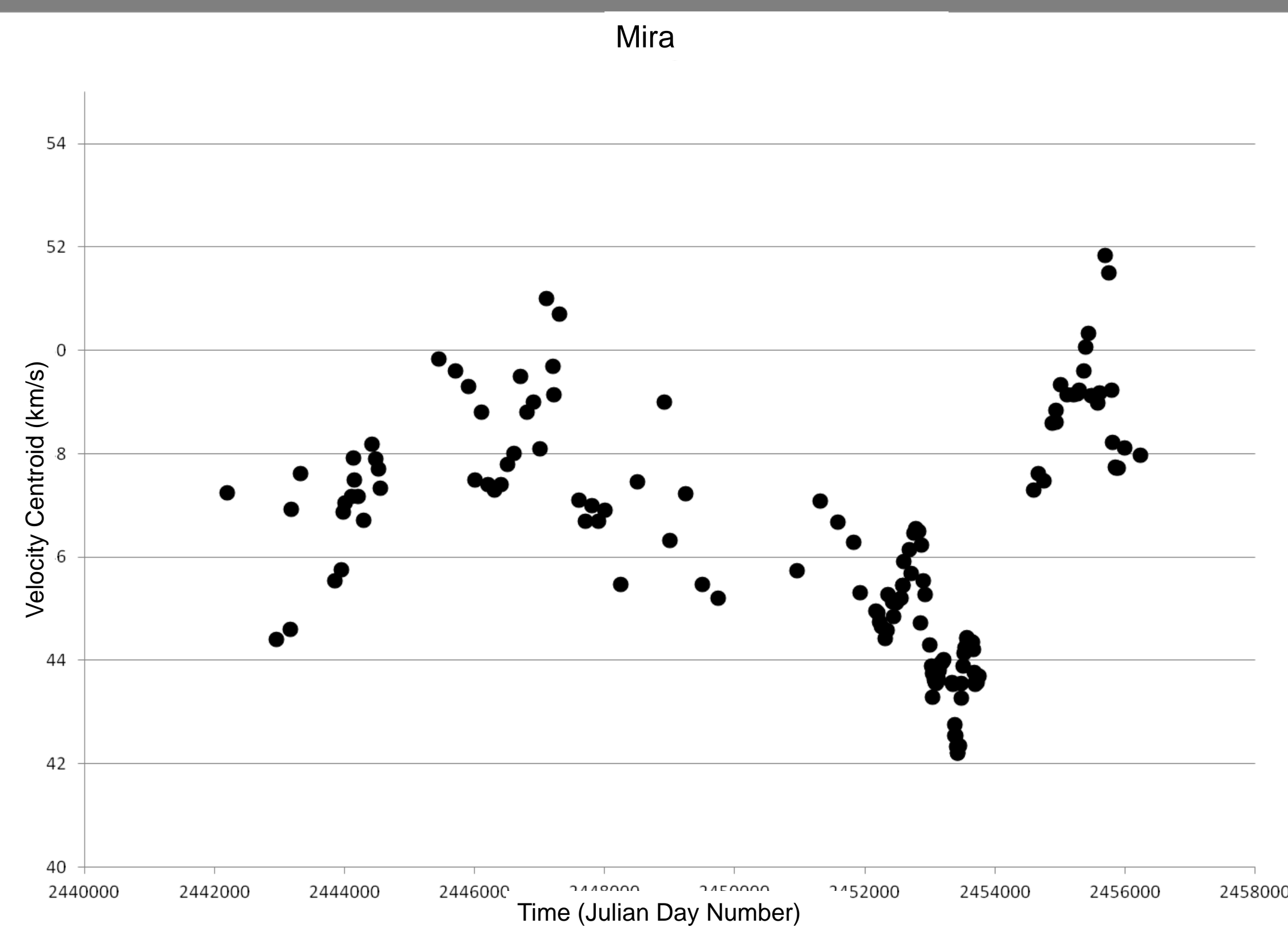
UNIVERSITY OF MINNESOTA
MORRIS